Calculation of service area for mobile communication system using optical rays

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CALCULATION OF SERVICE AREA FOR MOBILE COMMUNICATION SYSTEM USING OPTICAL RAYS

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Abstract: Communication systems using optical rays are expected to be used in environments containing sensitive electronic equipment. This paper studies a method of calculating the service area for an optical mobile communication system. The service area is defined by the communication angle, which is calculated using ray-tracing theory considering reflections from materials in the room. The calculated results are compared with experimentally measured ones, and the difference is less than 12%.

1. INTRODUCTION

Since an optical mobile communication system does not radiate electrical waves from mobile equipment, it is expected to be used in special electromagnetic environments that contain sensitive electronic equipment [1].

An optical communication system has been developed for use in a local area network (LAN) [2][3]. However, the receiver and transmitter must be fixed on an object, such as a desk or bookshelf, because optical communication rays are highly directional and it is difficult to maintain communication if they move.

A method of determining the directivity and placement of an optical receiver and transmitter needs to be studied. Some simulation methods for determining the placement of the fixed terminal using electrical waves have been reported [4], [5]. However, they can't be applied to optical mobile communication because they require that the directivity of the receiver and transmitter is broad.

This paper presents a simulation method using ray-tracing theory considering reflections from objects in a room. The service area is calculated from the communication angle. The calculated results are compared with the measured results to estimate the calculation error.

2. CALCULATION OF SERVICE AREA

2.1 Communication angle

In an optical mobile communication system, a mobile terminal exchanges data with a fixed terminal. The directivity of the receiver and transmitter is sharper than in radio mobile communications. In an optical mobile communication system, the angle over which communication is possible is the main factor determining the ease of communication. The fixed terminal should be placed so that it does not influence the mobile communication considering the directivity of the optical receiver and transmitter.

The communication angle is defined in Fig. 1. It is the sum of the angles over which it is possible to communicate when a mobile terminal is horizontally rotated 360 degrees.

2.2 Calculation of communication angle

Figure 2 shows a general propagation model from the optical transmitter to an optical receiver. The radiation of the transmitter can be expressed by a generalized Lambertian model [6]. Therefore, the light radiated from the transmitter is given by

$$R(\theta)=\frac{n_t+1}{2\pi}P_t\cdot\cos^{n_t}\theta \quad , \tag{1}$$

where P_t is total emitted power of the transmitter, θ is the angle subtended between the normal to the transmitter and the direction of the radiation, and n_t is defined by

$$n_t=\frac{\log(1/4)}{\log(\cos\theta_h)} \quad , \tag{2}$$

In Eq. (2), θ_h is the half-power angle, i.e., the angle at which the communication distance becomes half.

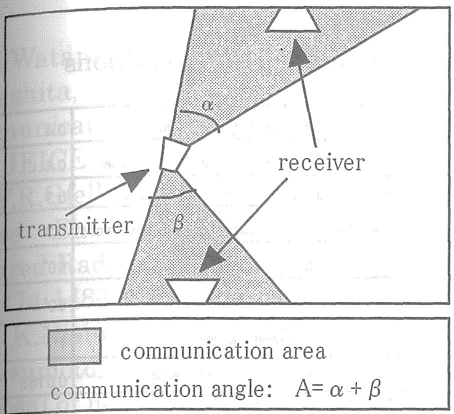

Fig. 1 Definition of communication angle

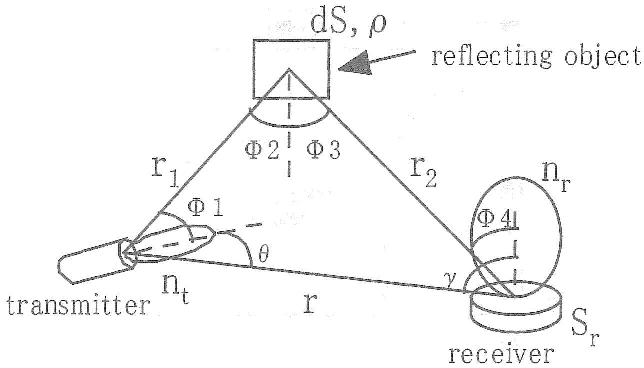

Fig. 2 Propagation model for optical mobile communication system.

According to the model in Fig. 2 and Eq. (1), The power of the direct wave R_0 is given by

$$R_0 = \frac{n_r + 1}{2r^2} R(\theta) \cdot S_r \cdot \cos^{n_r} \gamma \ , \tag{3}$$

where r is the distance from the transmitter to the receiver, n_r is the half-power angle of the receiver, S_r is the area of the optical receiver, and γ is the angle of incidence on the receiver.

It is assumed that an object reflects the light radiated from the transmitter by small area dS and the receiver also receives it. The power received by the receiver dR_i is given by

$$dR_i = \frac{(n_r + 1) dS_i}{2\pi r_{1i}^2 r_{2i}^2} \rho_i \cdot R(\phi_{1i}) \cdot \cos\phi_{2i} \cdot \cos\phi_{3i} \cdot \cos^{n_r} \phi_{4i} \ , \tag{4}$$

where r_1 is the distance from the transmitter to the reflection area of the object, r_2 is the distance from the transmitter to the reflection area of the object, ρ is reflection coefficient of the object, ϕ_1 is the angle subtended between the normal to the transmitter and the direction of the radiation, ϕ_2 is the angle of incidence on the object, ϕ_3 is the angle of reflection on the object, and ϕ_4 is the angle of incidence on the receiver.

Using the expressions in Eqs. (3) and (4), the total received power at an angle θ is given by

$$R_t(\theta) = R_0(\theta) + \sum_{i=1}^{M} dR_i(\theta), \tag{5}$$

where M is the number of reflecting materials.

The signal delay can be neglected when the transmission speed is below 1 Mbps because the transmission distance is less than 20 m and the delay time is less than 70 ns if the permeability of the propagation medium is omitted. Under this assumption, the communication angle satisfies the following conditions

$$R(\theta) > R_s \ , \tag{6}$$

where R_s is the threshold power for communication.

Using Eq. (6), the communication angle is calculated for the positions where you want to request communications. In addition, the distribution of communication angle can be obtained by applying this method over the entire area.

3. MEASUREMENT OF COMMUNICATION ANGLE

To verify the validity of the simulation method, we compared the simulation results with the measured results. Figure 3 shows the experimental set-up.

The room used for the experiment was an office, 6.3 m long 5.0 m wide, and 2.4 m high. Three partitions, each 1.8 m high, were placed in the room as shown in Fig. 3. The walls, floor, ceiling and partitions were assumed to be Lambertian reflectors. The conditions and reflection coefficients are summarized in table 1. Table 1 also gives the parameters of the

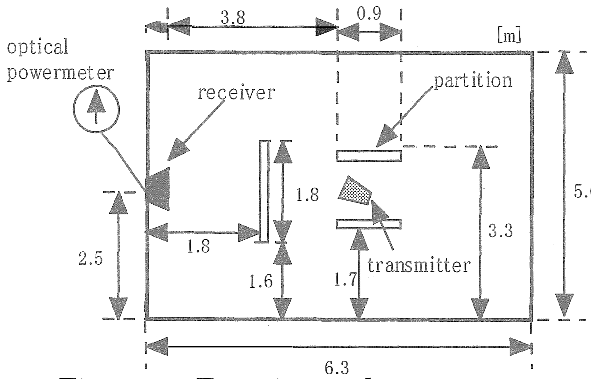

Fig. 3 Experimental set-up to measure communication angle

Table 1 Experimental conditions

Reflection coefficient	Walls: white paint and flat surface	0.4
	Ceiling: white paint and flat surface	0.4
	Floor: gray paint and flat surface	0.3
	Partition: blown paint and flat surface	0.3
Half-power angle	Transmitter	60°
	Receiver:	60°
Total emitted power: P_t (normalized value)		1
Threshold receiving power: R_s (normalized value)		0.0165

optical communication system used for the experiment.

The optical transmitter was placed 1.5 m above the floor and rotated from 0 to 360 degrees. The tilt angle of the transmitter was set so that the maximum radiation angle agreed with the horizontal reference plane. The communication angle was obtained from the angle where the receiving optical power exceeded the threshold value. We measured 108 points for the communication angle, at a height of 1.5 m, that were separated by 0.5 m from each other. The results are shown in Fig. 4.

The calculated results were obtained using Eq. (6) and the constants listed in Fig. 3 and table 1. The results are shown in Fig. 5. Comparing these figures, we can see that the overall distributions of the communication angle roughly correspond. To evaluate the results, we defined the average error is

$$E = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{x_{c_i} - x_{m_i}}{x_{c_i}}\right|, \quad [\%] \qquad (7)$$

where x_{c_i} are the calculated results, x_{m_i} are the measured results, and N is the number of the measurement points.

The average error was about 12% when the values for the measurement points were individually compared. This means that the calculation method presented in this paper can be applied to a simulation to determine the location of the fixed terminal and the directivity of the optical mobile communication terminals.

4. SIMULATION

First, we simulated the relationships between the communication angle distribution and the number of receivers. Figures 6 and 7 show the simulation results for two and four receivers, respectively, using the same environment as in Fig. 3.

We calculated the fraction of the area where the communication angle was 360 degrees. For one, two, and four optical receivers, the ratio was 47%, 83%, and 83%, respectively. Therefore, if two optical receivers are set up in this room, communication is possible almost everywhere in the room.

5. CONCLUSION

We simulated the placement of the fixed terminal and the directivity of mobile terminals. The communication angle was proposed as a parameter for evaluating the communication area of an optical mobile communication system. Our method of calculating it using a ray-tracing technique gave results within an error of 12% of the measured values. Simulation results indicate that two fixed terminals are needed for adequate communications.

In future work, the calculation method should be extended to consider noise from fluorescent light.

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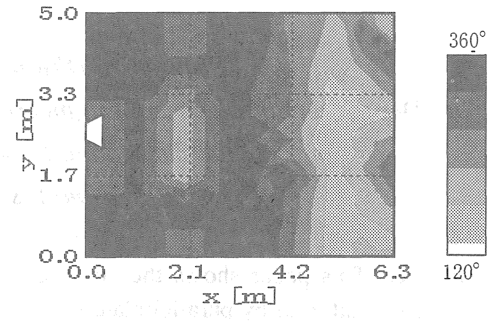

Fig. 4 Contour map of measured results

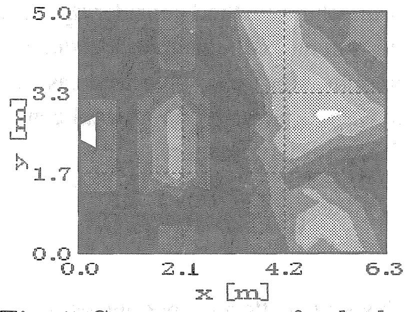

Fig. 5 Contour map of calculated results

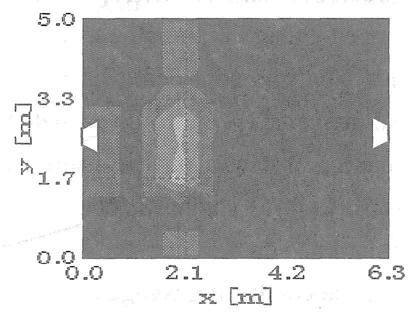

Fig. 6 Contour map of simulation results for two receivers

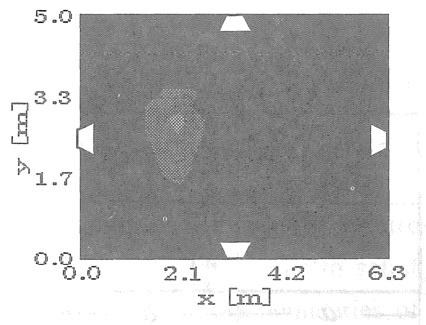

Fig. 7 Contour map of simulation results for four receivers